

# **Evaluation of an *In Situ* Absorption and Beam Attenuation Meter in Clear Open Ocean Water**

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## **LONG-TERM GOALS**

Our goal is to assess and characterize *in situ* inherent optical property (IOP) observations in the clear natural waters of the Sargasso Sea. *In situ* IOP determinations are difficult in clear waters due to the fact that the signals are extremely small relative to “pure” water used to calibrate the instrument. The emphasis of our research is to develop methods for making accurate and precise IOP measurements made with a WETLabs AC-9 spectral absorption and beam attenuation meter in the clear natural waters of the Sargasso Sea and to validate these measurements against independent, *in situ* apparent optical property (AOP) and *in vivo* IOP determinations. The development of methodologies for making accurate IOP profiles for this highly demanding environment will lead to an increased understanding of this important instrument for all waters.

## **OBJECTIVES**

Our near-term objectives are to, 1) characterize the precision of *in situ* IOP determinations by examining inter- and intra-cruise variations in the measured beam attenuation and absorption spectra, 2) determine the accuracy to which the *in situ* IOP measurements can be made by comparing with other relevant data sets, 3) evaluate the temporal-depth patterns in IOP values at U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) site and 4) address the relationship between *in situ* IOP values and simultaneously observed biogeochemical property variations.

## **APPROACH**

Our approach is to deploy a WETLabs AC-9 instrument on all BATS cruises along with detailed *in vivo* IOP, AOP and biogeochemical determinations are made. We have developed data processing tools to collect, process, correct and analyze AC-9 IOP values concurrently with other measurements made at the BATS site. We also perform “pure” water and air calibrations before and after each 4 day cruise. This extensive data set will give us enough data to distinguish natural and instrument signals. We evaluate the consistency of the *in situ* IOP signals by comparing them with the *in vivo* IOP determinations. We also assess the *in situ* IOP signals using the HYDROLIGHT radiative transfer model (Mobley, 1995) as a basis of comparing with the AOP determinations (Brody, 1998).

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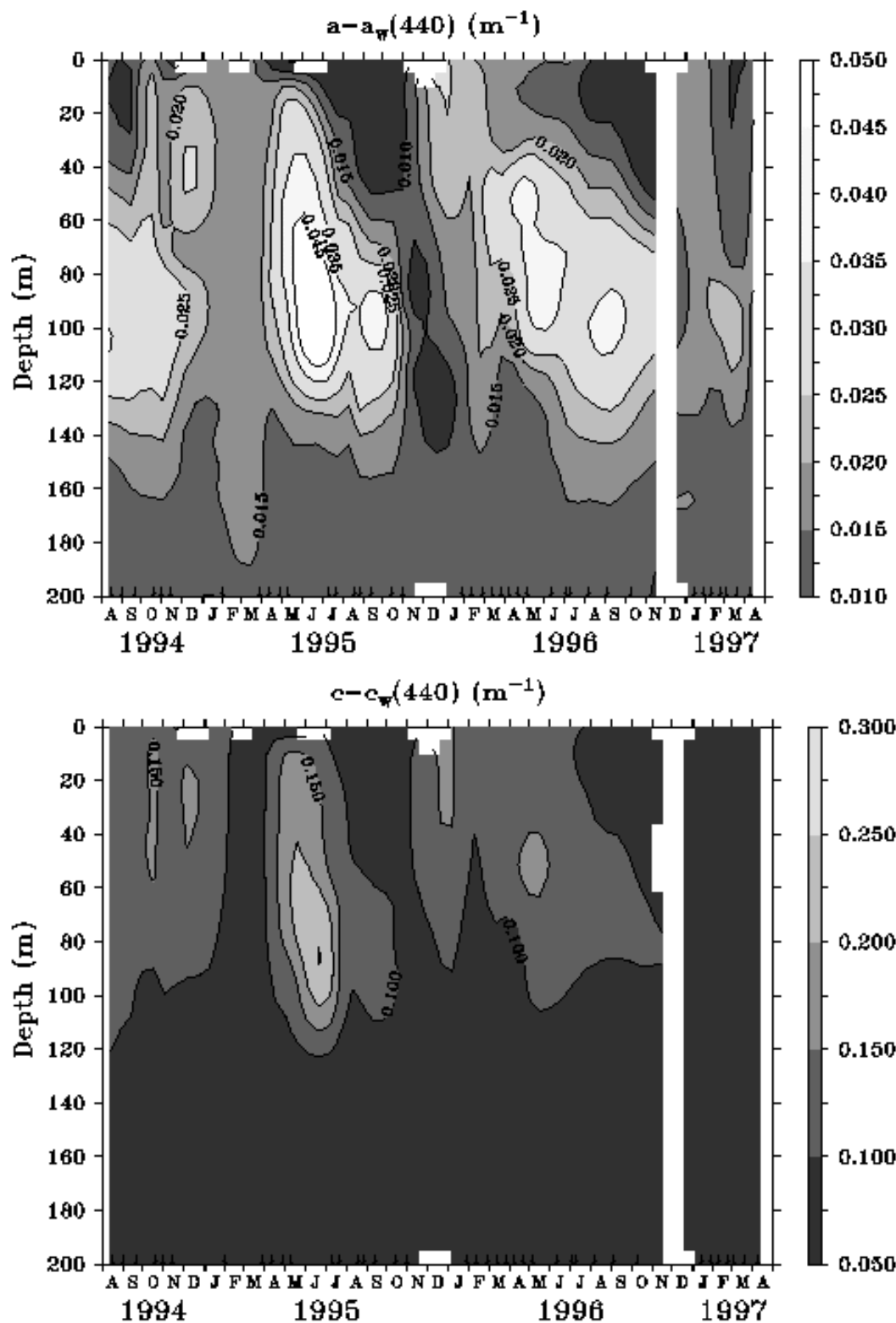
## WORK COMPLETED

We have made monthly *in situ* IOP profile observations on all BATS cruises for the past four years (a total of 39 cruises in total). All data are analyzed and merged with the BBOP AOP data set using the BBOP data processing system (Siegel *et al.* 1995a). In April 1996, we installed a “pure” water calibration system in Bermuda working WETLabs personnel. Since then we have been making pre-, post-, and inter-cruise air and water calibrations with the WETLabs AC-9. We have conducted many of the direct comparisons with the ancillary data sets. A masters thesis by Mr. Eric Brody describes most of the work accomplished to date (Brody, 1998) and we expect to have a manuscript summarizing these results submitted sometime this coming spring.

## SCIENTIFIC RESULTS

Accurate *in situ* IOP determinations are difficult to obtain in clear waters due to the fact that the IOP signals are extremely small relative to “pure” water used to calibrate the instrument. Hence, we have found it difficult to employ our pre- and post- cruise pure water calibrations to the *in situ* data set. Differences in “pure” water calibrations have been observed as large as  $0.05 \text{ m}^{-1}$  which are larger than the magnitude as the natural IOP signals we are attempting to measure!! Hence, we have developed new methods for “vicariously calibrating” the AC-9 signals using the BBOP AOP and physical oceanographic data set (Brody, 1998; Brody *et al.* 1999). After applying these corrections, we have collected and analyzed depth and time distributions of *in situ*  $a(\lambda)$ ,  $c(\lambda)$  and, by difference,  $b(\lambda)$  spectra for the open ocean. These observations are the among first of their kind and we are presently completing a manuscript describing the vicarious calibration method and the interpretation of the *in situ*  $a(\lambda)$ ,  $b(\lambda)$ , and  $c(\lambda)$  spectra (Brody *et al.* 1999).

Examples of the time-depth distribution of *in situ* IOP's are shown in figure 1a for the non-water absorption coefficient ( $a'(440) = a(440) - a_w(440)$ ) and in figure 1b for the non-water beam attenuation coefficient ( $c'(440) = c(440) - c_w(440)$ ; see also Brody *et al.* 1996). First, values of  $c'(440)$  are always greater than  $a'(440)$ . Second, the time-depth patterns of



*Figure 1: Time-depth distribution of the non-water absorption coefficient ( $a'(440) = a(440) - a_w(440)$ ) and the non-water beam attenuation coefficient ( $c'(440) = c(440) - c_w(440)$ ) for the three years of BBOP observations. Plus signs on the bottom of each plot indicate when IOP profiles are taken.*

$a'(440)$  follow the chlorophyll pigment distributions (see Siegel *et al.* 1995b). Third, the  $c'(440)$  patterns have higher values near the sea surface, but decay below the depth of the seasonal thermocline. In all, the basic time-depth patterns are as expected. We are now in the process of validating these data against independent data and interpreting them in relation with the independent AOP observations. Consistent spectral patterns for the *in situ* IOP's are also observed. Spectral absorption derived from AC-9 resemble the corresponding *in vivo* spectra ( $a_p(\lambda) + a_g(\lambda)$ ) with chlorophyll peaks at 440 and 675 nm in the upper 50 m. At deeper depths, declining exponential shape of absorption is observed.

As described previously, one of our primary goals is to assess the accuracy and precision of the WETLabs AC-9 instrument. We can show this by assessing *intracruise* and *intercruise* variability at depth (200 m) where we expect the smallest natural IOP variability. The average *intracruise* precision of the AC-9 signals is 0.007 and 0.002  $\text{m}^{-1}$  for  $c(440)$  and  $a(440)$ , respectively. This indicates that the corrected AC-9 signals are routinely precise measures of the inherent optical properties. However, *intercruise* variations at depth are much larger (0.013 and 0.015  $\text{m}^{-1}$  for  $c(440)$  and  $a(440)$ , respectively). Fortunately, this is similar in magnitude to *intercruise* variations in the *in vivo* absorption coefficient for colored dissolved organic materials ( $\sim 0.01 \text{ m}^{-1}$ ) measured at the same time. These and other comparisons are encouraging indicating that the AC-9 spectral absorption and beam attenuation meter produces reasonable IOP estimates in clear waters *if the data sets are properly cared for*. This work is on-going and *in situ* IOP and other data will be continued to be collected at BATS.

## IMPACTS/APPLICATIONS

We have obtained, calibrated, processed, analyzed and validated *in situ* profiles of spectral attenuation, absorption and scattering coefficients for data collected over a four-year period in the clear natural waters off Bermuda. Potential sources of uncertainty have been identified and a "vicarious calibration" procedure has been developed based which requires simultaneous AOP and physical oceanographic observations. Using the final IOP data set, the temporal, depth and spectral variations of the *in situ* IOP parameters exhibit realistic variations.

## TRANSITIONS

It is difficult to assess directly the impacts our work has had. Over the past four years, we have worked closely with the manufacturer of the AC-9 (WETLabs, Philomath OR) and have gently coerced them into making a series of design and calibration procedure improvements. This has made present versions of the AC-9 (and their new HiSTAR) instruments much more stable and capable for working in blue water environments.

## RELATED PROJECTS

The U.S. JGOFS Bermuda Atlantic Time-series Study, BATS) is focused on the determination of time variability of biogeochemical fluxes at a site 75 km SE of the island of Bermuda. Ship time used for this project is provided by the BATS program.

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